AN ANALYTICAL STUDY OF EARTH PRESSURE MEASUREMENTS ON OPEN CUTS, CHICAGO SUBWAY

BY

TIEN-HSING WU

B.S., St. John's University, 1947
M.S., University of Illinois, 1948

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Scope Of Investigation

During the construction of the initial subway system in Chicago in the years 1937 through 1941 field observations were made on the open cut portions. The results of these measurements and a comparison between the observed and theoretical earth pressures were presented by Prof. R. B. Peck in his paper, "Earth Pressure Measurements in Open Cuts, Chicago Subway", Trans. ASCE, 1943. Preliminary analyses indicated that the values of the hydrostatic pressure ratio K_A as obtained by Rankine's Theory and those obtained by the General Wedge Theory differed only by an insignificant amount for the range of variations in the measured centers of pressure. Hence the observed pressures were compared with those computed on the basis of Rankine's Theory. It was found that the observed and theoretical earth pressures were in satisfactory agreement with each other. The agreement was most consistent for a value of ϕ equal to 0 degree and a value of n equal to 0.75, where ϕ denotes the angle of internal friction of the clay and n the coefficient of progressive failure. The measured movements of the sheeting were of such a nature as to develop arch action in the soil, resulting in the observed non-hydrostatic pressure distribution.

Since the completion of the initial system of the Chicago Subway, additional field data have been obtained from Open Cut D8 in the extension of the Dearborn Street Line. This portion of the Subway was constructed during the years 1947 to 1949. The cut had a maximum depth of 63 ft. which was considerably deeper than that of any of the open cuts previously studied.

The object of this investigation is to study the applicability of the existing earth pressure theories derived on the basis of

mobilizing the full shearing resistance of the soil along a surface of failure. The measured earth pressures given in Prof. Peck's paper and those obtained from Cut D8 have been analyzed by the General Wedge Theory. Other factors considered include the effect of progressive failure in clay, the effect of movements of the sheeting and the distribution of earth pressure.

Field Measurements On Open Cuts, Chicago Subway

The temporary structures constructed for bracing the sides of the open cuts in the Chicago Subway were of two types, continuous steel sheet piling and H-piles at various spacings with timber lagging between them. Both types were braced with horizontal wales and struts. The excavations varied from 15 to 55 ft. in width and 35 to 63 ft. in depth.

The program of field measurements consisted of the measurement of strut loads, observations of the movements of the sheeting, and measurements of the settlement of the nearby buildings and adjacent ground surface during the progress of excavating the cuts.

The subsoil at Chicago in the area concerned consists of sand varying from 8 to 16 ft. in thickness. Beneath the sand is a thin layer of stiff clay. A thick deposit of the plastic Chicago blue clay underlies the stiff clay. This deposit is of soft to medium consistency to a depth of about 40 ft. Below this depth the strength of the clay steadily increases and the clay becomes very stiff at about 55 ft. below the ground surface.

Soil investigation disclosed that the strength of undisturbed samples of the clay was about 1.35 times the strength obtained from Shelby tube samples. The strength of undisturbed samples was used in all computations.

Analysis Of Earth Pressure By The General Wedge Theory

The General Wedge Theory was used to compute the earth

pressures against the bracing of the cuts. Preliminary analysis indicated that only results obtained with a value of ϕ equal to 0° were comparable with the measured earth pressures. Hence, all subsequent analysis were made for a ϕ of 0°.

It was believed that the coefficients of progressive failure should be different for the stiff and soft clays. The two values are denoted by n_1 and n_2 respectively. It is known that for the soft clay, the value of n_1 is close to unity. On the other hand, the strength of the stiff clay is greatly reduced by the presence of fissures and joints. Furthermore, the stiff clay reaches its maximum strength at a strain far below that required to develop the maximum strength in the soft clay. After passing the peak strength, the stiff clay undergoes a very large loss of strength. A value of n_2 in the range from 0.2 to 0.4 would therefore seem reasonable.

The proper value of n_2 was evaluated by comparing the measured pressures with the pressures computed with various values of n_2. Since the thickness of the stiff clay does not exceed 9 ft. in any of the cuts whereas the depth of the cuts varies from 27 to 60 ft., the difference between the computed pressure and the measured pressure should be a consistant quantity only if n_2 is estimated correctly. Otherwise the difference will show a systematic tendency to change with the depth of the cut. The comparison indicated that the relation between the observed and theoretical pressures is most consistent for a value of n_2 equal to 0.20.

Comparison between the computed and measured earth pressures led to the following conclusions.

The measured earth pressures provide an excellent verification of the General Wedge Theory for computing earth pressures against the bracing of open cuts. This confirms that the problem may be considered as one of a wedge of soil tending to slide forward upon an incipient surface of sliding, and that the shearing strength of the soil is fully mobilized to resist this tendency.

Pressures computed by the General Wedge Theory for a

surface of sliding extending to the bottom of the cut agree with the measured earth pressures within ± 20%. When the surface of sliding is extended to the top of the stiff clay or the bottom of the sheet piles, the agreement is equally satisfactory, provided the resistance of the soil below the bottom of the cut can be estimated correctly. The relation between the computed and measured earth pressures is consistent. No trend for change with changing depth of cut or with changing average strength of the clay can be observed.

The soil below the bottom of the cut can be relied upon to develop a resistance up to its unconfined compressive strength. The amount of resistance that will be developed depends on the amount of movement of the soil and the relative strengths of the materials above and below the bottom of the cut.

Computations with the surface of sliding passing through the bottom of the cut do not involve the uncertainty of the amount of resistance that can be developed at the bottom of the cut. The earth pressures determined by this method were generally the maximum values. In cases where the maximum values were obtained with a deep surface of sliding, they were not appreciably greater than the results of computations with the surface of sliding passing through the bottom of the cut. Hence it appears justifiable to assume that the surface of sliding passes through the bottom of the cut in the computation of earth pressures on bracings of open cuts if the conditions of the soil and type of bracing are similar to those here studied.

Distribution Of Earth Pressure And Deformations

The measured earth pressures indicate that the deformation conditions of the sheeting exert a striking influence on the distribution of earth pressure. If the bottom of the sheeting is relatively free to yield, the distribution is usually parabolic, but if the sheeting penetrates into a very stiff stratum a triangular distribution results.

Regardless of the type of pressure distribution, the total measured pressures at any section remain in consistent agree-

ment with those computed by the General Wedge Theory. The measured pressures always range between 1.0 and 1.5 times the pressure computed by Rankine's Theory.

For the depths of the cuts considered, settlements immediately adjacent to the cuts may reach the order of 0.5 to 1.5% of the depth of the cut. This settlement decreases with increasing distance from the cuts and becomes negligible at about 60 ft. away from the edge.

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VITA

Tien-Hsing Wu was born in Shanghai, China on March 2, 1928. He entered St. John's University in June 1944 and received the degree of Bachelor of Science in Civil Engineering in June 1947. He began his graduate study at the University of Illinois in Sept. 1947 and received the degree of Master of Science in August 1948. In September 1949, he was appointed Research Graduate Assistant at the University. He worked with the Alaska Railroad as a Junior Engineer during the summer of 1950.

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